Intelligent Vision Systems IR&D 2006

Interim Report
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This report summarizes results in conduct of research sponsored by the 2006 Independent Research and Development (IR&D) program at Marshall Space Flight Center (MSFC) at Redstone Arsenal, Alabama. The focus of this IR&D is neural network (NN) technology provided by Imagination Engines, Incorporated (IEI) of St. Louis, Missouri. The technology already has many commercial, military, and governmental applications, and a rapidly growing list of other potential spin-offs. The goal for this IR&D is implementation and demonstration of the technology for autonomous robotic operations, first in software and ultimately in one or more hardware realizations. Testing is targeted specifically to the MSFC Flat Floor, but may also include other robotic platforms at MSFC, as time and funds permit.

For the purpose of this report, the NN technology will be referred to by IEI's designation for a subset configuration of its patented technology suite: Self-Training Autonomous Neural Network Object (STANNO).

Background and Theory

STANNOs have already been developed to a highly-advanced level of capability through many years of experimentation. Implementation for specific tasks is often accomplished in minutes or hours, building upon a set of experience and tools previously groomed and tested in various other operations. However, to date STANNOs have been realized only in software form, the most recent of which executes on a high-power laptop computer. If the target system is too small to house and power the laptop, as is often the case with small robotic platforms in particular, the connections are made by external umbilical.

This IR&D states as one intended product -- provided continuation into at least one additional year of funding -- the realization of STANNOs in hardware form. That form will most likely be grids of interconnected Field Programmable Gate Array (FPGA) devices. These grids are commonly called an "FPGA Fabric," as they knit together any number of FPGA devices, often along with other supporting electronics such as microprocessors, memory, and communication processors.

Figure 1 shows a diagram of one configuration of STANNO technology. In this scheme, feedback topology is shown as a part of the NN module. This illustrates the core means by which the NN trains itself: human interactions in effect involve only the instruction of the NN in its assigned objectives, relying upon the STANNO to perform the more detailed and intensive neural training. The STANNO arrives at its interim or final trained

configurations by experimentation, evaluation of the results, and updated programming of neural weights. When the weights are locked and cannot be further changed, the network is considered "static." Allowing the weights to continue training during operation categorizes the network as "dynamic."

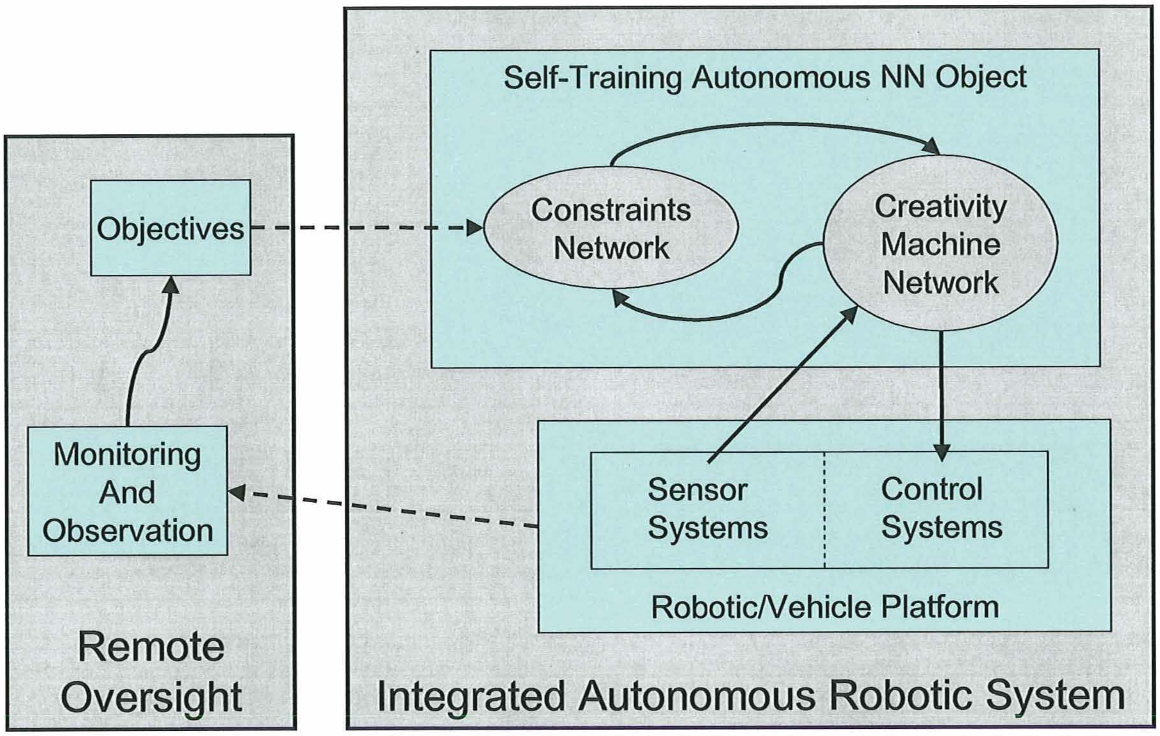

Figure 1: System Conceptual Diagram

The Creativity Machine itself is patented technology that absorbs knowledge of the problem space under consideration and then explores "confabulations" of the information to arrive at new possibilities for solutions. Through a carefully controlled application of stimuli to the network, new and often surprisingly unique results are output for consideration.

A very exciting aspect of this technology is that the NNs not only learn behavior that can be creatively manipulated, but also learn the constraints which are to be applied to the operational system. This compares very favorably to other techniques, including other NN technologies and Genetic Algorithms, which require a full knowledge of the problems space's constraints prior to training or programming the intelligent core.

A very important possibility opens up to experimenters in view of the modular nature of STANNO technology. Consider making the Constraints Network static while allowing the Creativity Machine to continue in dynamic operation. This scheme retains the benefits of dynamic network adaptation while keeping responses under fixed constraints. In fact, the Constraints Network can then potentially have standardized Independent Verification and Validation (IV&V) applied in order to facilitate man-rating or other qualification.

Early Results

In a set of impromptu experiments carried out on MSFC's Flat Floor during a visit in May 2006, IEI's Dr. Stephen Thaler demonstrated basic capabilities of STANNO technology in application to autonomous docking. Using a Logitech webcam plugged into his laptop and taped to the top of the air sled, along with an image recognition package developed for another purpose, the STANNO was trained on four discreet images of the docking target representing four distances from the target which were approximately evenly spaced. Further, each of these images was approximately centered on the vertical midline of the target.

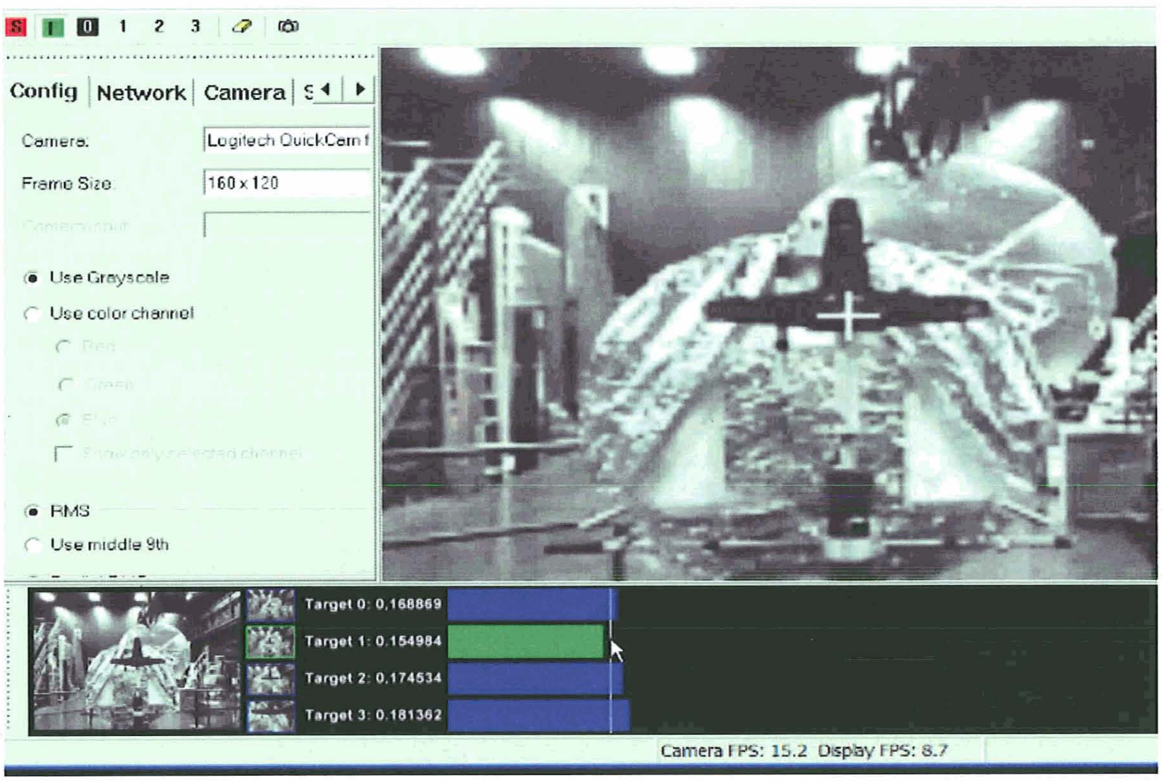

Figure 2: Early Flat Floor Experimentation

In video footage resulting from this exercise, as shown in Figure 2, the STANNO is shown capable of not only identifying images in which white crosshairs are nearly centered on the target, but also identifying which range of distances to the target is most closely represented. Thus, the very rudimentary experiment shows how we may expect to estimate both alignment with and also range to the target.

It should be noted that this was accomplished in less than an hour of actual time on the Flat Floor, and less than one minute total training STANNOs to recognize the four images. Furthermore, we emphasize that the work was done without stereo imagery, with a commercial webcam purchased for about $70.

First Scheduled Flat Floor Visit

In early September 2006, IEI's Dr. Thaler and Dean Vieau returned to MSFC to carry out testing on the Flat Floor. The first several days were spent carrying out connection of the IEI laptop into the air sled's control circuitry. Cabling was introduced to bypass the usual LabVIEW-based laptop system usually utilized in commanding air thrusters on and off to control the sled.

The remainder of the visit was spent implementing schemes to adapt outputs from a pair of cooperating STANNOs tasked with sensing the need to rotate the sled clockwise or counterclockwise in order to align with the target. In this case, the thruster commands were designed in logic in LabVIEW on the IEI laptop, in order to give researchers the chance to become more comfortable with the behavior of the air sled. Such caution seemed prudent because of restrictions on rates of motion in use of the sled, and general unfamiliarity of the researchers with the hardware. In addition, only rudimentary braking control was implemented initially, so hard dockings were generally not a goal in this series of experiments.

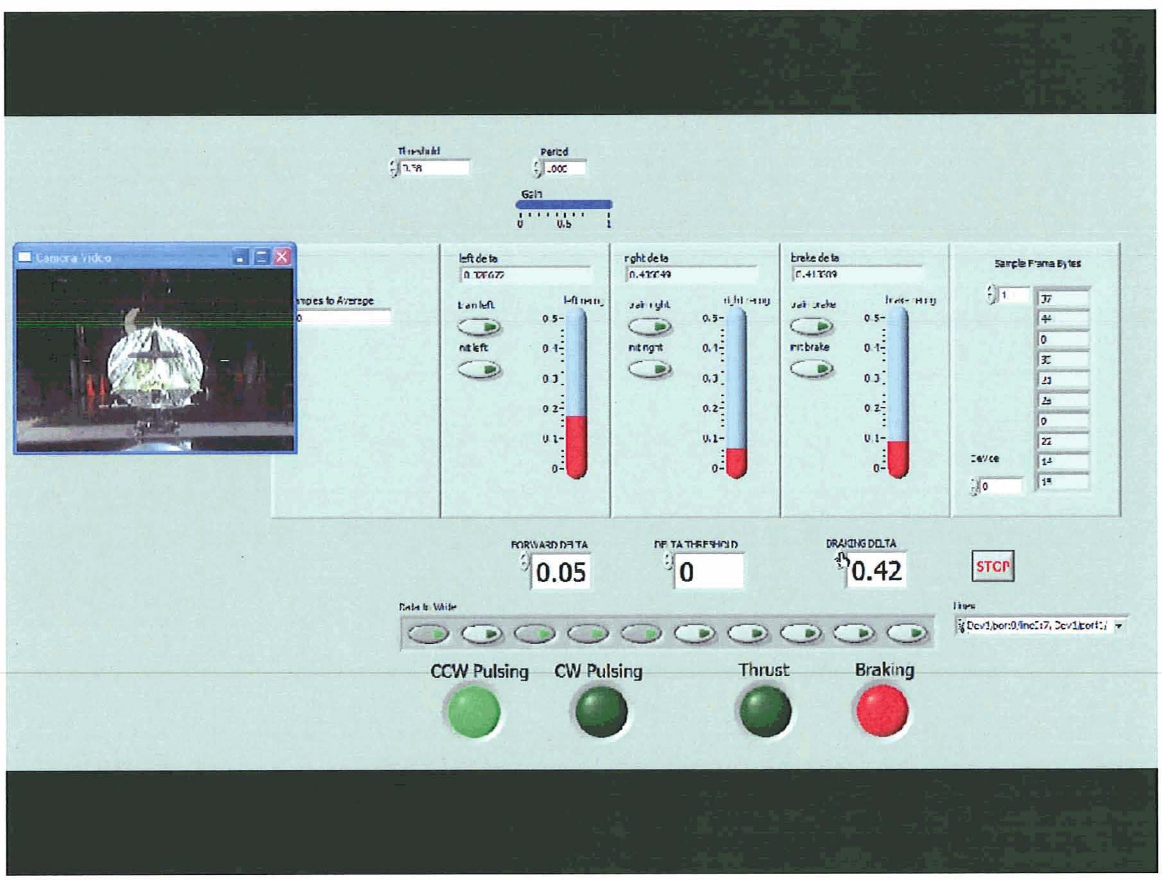

Figure 3: Front Panel Display during Tests

After sufficient assurance of basic control and safety, a number of sequential runs with the air sled showed that the STANNOs were capable of accomplishing rendezvous with

the target and initial action to take up station keeping at a range of about 3 meters. At this point it was discovered that because of the positions of the braking thrusters, natural mismatching of their individual thrust power, and imbalance of the mass on the sled itself, braking caused the sled to veer off-axis and lose contact of the camera system with the target. Because searching for the target when out of view was not yet implemented, this generally terminated test runs.

Nevertheless, in several tests the system was satisfactorily aligned and under control at the standoff point prior to brake firing, and in at least one case the sled managed to recover and all but fully dock with the target; because braking was not implemented closer than 3 meters, hard docking was prevented manually. Figure 3 is an image of the laptop display during this run. Note the small white marks (plus signs or crosshairs) to either side of the central object in the video frame in the upper left; these represent the centers of interest of the two STANNOs.

Plans for Continued Work

The next step in planned work is to give STANNOs complete control over the air thrusters, with certain constraints in place for safety and efficacy. This will allow the NN to demonstrate its ability to experimentally learn air sled operation and then control it in autonomous docking. In addition, it will allow the NNs to learn to not only compensate for differences in thrust force from one air thruster to another, unequal placement of thrusters, and imbalances in sled load, but also to accomplish reasonably smooth motion overall. In fact, given enough time to do so, it should be constructive to operate dynamically and allow the NN to compensate for induced thruster dropouts, shifts in sled load, and other changes to the sled's characteristics.

The ranging capability will be calibrated against existing ranging instrumentation on the sled, and then the NN will independently carry out a series of exercises designed to replicate standard Flat Floor docking work. Subsequent experiments will build upon these results, yielding capabilities not typically encountered in Flat Floor operations.

First, the STANNO-controlled sled will carry out autonomous docking from an initial attitude with the docking target already in view and the air sled orthogonally aligned with the target. Continuing exercises will progressively show the ability of the NN to successfully achieve autonomous dockings from non-orthogonal initial alignments and alignments which start without the target initially in view, or even with the target obscured by intervening objects.

In the meantime, planning and progress are being made on implementation of STANNOs in massively parallel reprogrammable hardware and other hardware platforms. Ultimately, it is expected that the processing will be done completely in hardware, making it possible not only to realize exceptionally dramatic increases in operational speeds, but also to implement more and larger networks.